

ROAD TRANSPORT SOCIAL COSTS IN SPAIN: A NEW RATIONALE FOR PRICING POLICY

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ABSTRACT

Like all EU countries, Spain should design and promote a fair and homogeneous generalized road pricing scheme. Tolls should vary according to infrastructure damage, degree of congestion, risk of accident, and environmental nuisances. An initial study (Spanish road pricing model project: META) of interurban transport pricing has been carried out at national level, considering the valuation of the internal and external costs to define efficient road pricing schemes of different type of roads and appropriate price levels in different interurban road contexts, shifting from a toll for financing infrastructure construction to a toll for recovering social costs.

The META project has developed an easy-to-apply pricing methodology, based on a bottom-up approach. The main variable is the AADT -daily flow- applied to accurately estimate generalized road transport costs for each kind of vehicles and each type of road. Based on the current Spanish road network, the META model estimates all social costs: internal costs (fuel, vehicle maintenance, labor, insurance and tax) and

external costs (infrastructure, congestion, accident and environmental nuisances). Computed for the 13,156 Km of interurban highways network, the model calculates the costs for each vehicle type (Car, HGV, LGV and bus) and for each road network section following the interurban road characteristics (AADT, capacity and traffic composition for each section of highway network).

The two main results of META model for costs in terms of policy implications suggest to moderate the construction of new interurban road infrastructures in Spain and to analyze congestion before to built new metropolitan roads. If we decide for a road pricing scheme based on the environmental, accident and infrastructure costs, because of the reduced number of the congestion situation, we can use the average external costs that are very similar to the marginal external costs.

Key words: Road costs estimation, External Costs, Internalization, Roads Pricing.

INTRODUCTION

The European Commission has advocated the reform of transport pricing, so as to harmonize transport policies and make more efficient the transport system by making the market conditions more similar in the member countries. Since 1970, the EU has been trying to establish a pricing policy that is fair and acceptable for all countries (EC,1970). The European Commission's Green Paper "Towards Fair and Efficient Pricing in Transport" (EC,1996) launched a discussion on pricing transport according to the marginal cost and the recovery of fixed investment costs. The White Paper "Fair Payment for Infrastructure Use" (EC, 1998) took this approach a step further, and presented a gradual path for implementing all transport modes, which was then adopted in the White Paper "European Transport Policy 2010: Time to decide" (EC, 2001). The main goal was to ensure that each transport mode pays for the costs its operation produces. Transport taxes and prices should vary according to infrastructure damage, degree of congestion, risk of accident, and environmental nuisances.

In parallel, more regulation of transport pricing has been developed by EU directives. The 1999/62 EC directive allows member countries to introduce a distance related charge for using European highways to cover construction, maintenance, and exploitation costs. This earlier directive was modified in 2006 by Directive 2006/38/EC on the charging of HGVs for the use of certain kinds of infrastructure. This more recent Directive paved the way for the introduction of charges on vehicles and especially HGVs in the EU countries, based on the distances they travel and the

estimated resultant pollution. A new objective of this charge is to cover the costs of both pollution and congestion. But the necessary legal criteria to define how, and when, to collect the pollution charge have still not been formulated. As a consequence, the EU countries possess neither the necessary incentives, nor explicit conditions made clear, for implementing such a charge. Only the new directive project of 2008/0147/EC tries to define reliable methods for estimating pollution and congestion costs and to calculate the appropriate road charge for each kind of vehicle. In any case, the EU directives are guidelines which have to be implemented by each country in the way they prefer, following the “subsidiarity principle” (Jaensirisak S., M. Wardman, and A.D. May, 2005).

Some countries have already adopted a charge for highway use. For instance, according to a 1999/62 EU directive, Austria and Germany moved a few years ago to a distance-based charging approach for HGVs over 12 tons (Link, H., 2007). Recently, the Czech Republic also adopted an approach similar to that of Austria and Germany (Chlan, A., 2008). Switzerland, even though it is not a member of the EU, has been charging HGVs above 3.5 tons for use of Swiss roads on all their roads since 2001 (Balmer, U., 2004).

Spain has 13,156 Km of interurban highways network (MIFO, 2007), of which only 2,814 km of those highways are tolled sections. Like other EU countries, Spain is obliged to consider the European Union’s transport policy and regulations designed to define, and promote, a fair and homogeneous generalized road pricing scheme. An initial study (META) of interurban transport pricing has been carried out at the national level, where the major debate is about the relative efficiency of different road pricing instruments and what the appropriate price levels should be in different interurban road contexts (Saurí et al., 2010).

The objective of this paper is to develop a methodology to evaluate the social costs including internal and external costs of traffic roads, where the internal costs contains time costs (without congestion cost) and operation costs (fuel consumption, lubricant etc.) and external cost includes infrastructure, CO2 cost, pollution cost, accident cost, congestion noise costs. We consider infrastructure maintenance costs like an external cost because currently are mainly paid by the government general expenditure, finally by the society. In this context, a model for road costs is implemented into the road network data to estimate the social costs in Spain. Based on the real daily flow data, the road social costs were estimated for a group of road section classified by a clustering process. All roads sections were classified firstly by the number of lanes and secondly by three different variables: average daily flow, proportion of HGV and floating vehicles speed (a proxy of the space speed). K-meaning method is used to cluster each type of highways (2+2, 3+3 and 4+4 lanes).

By this process we obtain, for each type of highways, two typical clustered road sections groups: a standard highways group, and another group of “intensive-use” highways. The implementation of the costs model to the height clustered groups of Spanish highways produces the estimation of the road costs for the selected road sections. Following this empirical costs model, the proposal for a toll scheme should include a price range for roads of 0.05€ per car-km to 0.14€ per HGV-km, defined like the difference between social and internal average costs. In this context, a toll scheme based on the marginal costs can be justified only in the metropolitan areas during peak hours.

The paper is divided into six sections. The first section—after the introduction—provides an overview of the current state of research on road pricing. The second section presents the characteristics of the current situation in Spain vis-à-vis the road pricing scheme. The third section describes the scope and the methodology to estimate the social costs by defining a costs model and applying a cluster methodology to implement the cost model to the road networks. The fourth section presents an analysis of the results. The fifth section proposes a vehicles tolling scheme based on average or marginal social costs depending on road traffic situations. The sixth section draws conclusions about implications for road pricing policy as a result of the road costs estimation.

STATE OF RESEARCH ON ROAD PRICING

Using road pricing as a means of allocating resources to optimise social welfare when congestion and other externalities arise has been analyzed in the literature for a long time. In the book *Economics of Welfare*, Pigou (1920) introduced the possibility of setting up prices to internalise the externalities of a given activity. During the last few decades in the transport field this approach has been particularly focused on pricing congestion in urban areas based on marginal social costs (Nash, 2007). However, in recent years there has been a growing trend towards charging all kind of vehicles travelling on the interurban highways network considering all external and the infrastructure costs as a means of internalizing the externalities they produce (Jansson J.O. and G. Lindberg, 1998; Suter and Walker 2001; Parry and Small 2005; Calthrop et al. 2007).

Since the publication of the Green paper on fair and efficient pricing (EC, 1996), the EC policy has postulated the “user pays” principle for charging the use of transport infrastructure. Apart from the Green paper, the major policy documents to define and implement charging policy in the UE are the White paper of 1998 on the fair payment

for infrastructure use (EC, 1998), the White paper from 2001 on European Transport Policy (EC, 2001) as well as directives and charging proposals for the specific transport modes.

The 1998 White paper defines the principle of social marginal cost pricing as the fair and efficient principle and suggests this as the leading principle for EU charging policy. In the subsequent policy documents such as the 2001 White paper, however, it is also recognised that there are situations where deviations from social marginal cost might be appropriate, provided that charges are non-discriminatory (for example in sectors where budget constraints are binding and thus cost recovery needs to be achieved). The legislative process to implement these principles at a modal level has been slow. On the road sector, there are two relevant directives: First, the Eurovignette directive (1999/62/EC) and second, a modification of this directive (EC 2006/38/EC). The 1999 Directive applies to vehicles above 12t max GVW and allows charging only on motorways whereby the charging principle is an average cost principle restricted to infrastructure costs (cost of construction, maintenance and operation). The 2006 Directive extends charging to the Transport European Networks and to roads which might be faced with diverging traffic. It applies to HGV above 3.5 t max GVW and allows to differentiate charges by distance, type of infrastructure, type of vehicle (axle weight, engine type, emission class etc.), speed, time of day as well as specific routes.

In general, there are three groups of countries with different traditions and motives behind road user charging. The first group comprises countries which historically relied on toll collection to fund highways development. This group includes France, Italy, Portugal and Spain, and more recently Greece, Croatia and Slovenia. A second group form the so-called Vignette countries which have within an EC agreement introduced the so-called EuroVignette for HGV. To this group belong Austria (until 2004), Germany (until 2005), Belgium, the Netherlands, Luxemburg, Denmark and Sweden. A third group of countries consists of Switzerland, Austria, Germany and recently the Czech Republic which have introduced distance-related HGV charges based on the relevant EU directives and, in the case of Switzerland as non-EU country, based on national policy goals and bilateral negotiations with the EU.

Most road pricing schemes are differentiated by combinations of vehicle characteristics such as:

1. number of axles and/or wheels (Austria, Germany),
2. weight of the vehicle (Hungary, Czech Republic),

3. height of the vehicle (Croatia, France),
4. length of vehicle (Netherlands),
5. foreign or domestic registered cars (Serbia),
6. emissions or fuel type (London),
7. number of passengers (Norway E39 - additional charges).

There are only few examples of charging schemes where charges directly vary by environmental criteria (emissions), by road condition (to support maintenance policy) or by level of service (except the fast lanes in U.S.). Notable exceptions are the use of discounts or exemptions for alternative fuelled vehicles (e.g. in the London Congestion Charge and the Pollution charge in Milan) or zero-emission engines (e.g. on express lanes in California). Environmental and pavement damage criteria may of course be addressed indirectly via the differentiation of charges according to vehicle classes.

The majority of current road pricing schemes are far from real-time congestion charging. Some systems, mainly in cities, discriminate between peak and off-peak times, but mostly in larger time slots. Examples with two or three different charges depending on time-of-day or peak/off-peak are the Trondheim Ring Road (Norway), the Stockholm Congestion Charge and the Highways in Portugal. Higher charges at peak times are generally achieved by offering off-peak discounts rather than by explicitly setting higher charges during the peaks. In Portugal, off-peak discounts are only available to users of the ETC pass ("Via Verde"). The systems which come closest to real-time congestion charging are the SR91 and IR15 express lanes in California and the road pricing scheme in Singapore. At the express lanes in California (State Road 91) the charges vary between weekdays and time of day (hourly) and the operator offers also different charges at public holidays. The aim of the pricing scheme is to provide a safe, reliable and predictable commute option with guaranteed speed. Drivers have the option of choosing ordinary, un-tolled lanes. The IR15 scheme, also in California, is even more advanced; here charges vary dynamically to reflect current levels of demand and are set at the lowest level commensurate with maintaining free flow traffic on the tolled lanes. Charges may move up or down several times an hour. Drivers are informed of the current charge as they approach the tolled lane and have the opportunity to continue their journey on the un-tolled lanes.

In the Singapore electronic road pricing (ERP) scheme the road charges vary in half-hourly time slots. Graduated rates have been introduced for the first five minutes

of the subsequent time slot which is characterised by a higher toll rate. In contrast, if the subsequent period has a lower rate, the new rate is introduced for the last five minutes. This applies to cases where the change in the rate is at least \$0.50, depending on vehicle type. For car drivers, the graduated rate applies where the change in rate is at least \$1. Rates are fixed for approximately 2-3 months and are reviewed in the light of expected demand during the next period.

Following the EU policy (Towards fair and efficient pricing in Transport, 1996) oriented to implement a tolling system based on social marginal costs, Spain is studying the implementation of an interurban road pricing scheme (Di Ciommo F., A. Monzón and A. Fernandez, 2010). A starting point is that prices should reflect the marginal social cost imposed on society from consumption of the good (v-km travelled). When car users decide to travel additional kilometres impose additional costs (Nash, 2007):

- on themselves (operating and time costs)
- on the infrastructure-provider (maintenance and operation costs)
- on other users (delay and congestion cost)
- on the rest of society (accident, climate change, pollution and noise).

Costs to other users and to the rest of society are referred to as external costs. These costs, specially the congestion costs, in general, are higher in the Metropolitan Areas. In fact, the estimation costs for the interurban road network in Spain shows that the marginal social costs are constant and similar to the average social costs. In consequence, in this case appear more appropriate and easier to propose a road pricing scheme based on the average external costs (Fang J., F. Di Ciommo, A. Monzón et al. 2009).

THE CURRENT SITUATION IN SPAIN.

The present pricing system for Spanish highways is quite fragmented. Some highway construction is financed by tolls on users through concession contracts, other highway construction is financed by shadow tolls, that is tolls paid not by the immediate user, but paid to the concessionaire by the government as part of its general expenditures. The regions of Madrid and Murcia have been the first ones where the public administrations have applied shadow toll schemes as a way to remunerate the highway concessionaires. Previously, the Central Administration did not employ the device of the shadow toll, fearing a possible risk of increase in its general budget spending (Vassallo, J.M. and R. Izquierdo, 2002). But new laws on the

concessionaire system introduce the possibility of using the shadow toll to finance road infrastructures (Vassallo, J.M. and A. Sanchez-Soliño, 2007). Related to this new regulatory perspective, more than 1,500 km of new regional and national highways will be financed by a shadow toll scheme. The Central Government is using this shadow toll scheme at present to finance the concessions contracts for the maintenance, renovation, and operations of the national highway network. At present, the highways where the direct toll is used amount to 2,814 km, while those that employ the shadow toll method of compensating concessionaires amount to 872 km. There is a plan to increase the highways relying on the shadow toll method to 2,275.15 km, possibly by the year 2010, according to the plans of the Department of Spanish Infrastructures (MIFO, 2007a). The highways with a direct toll will then account for 60% of the total kilometers under concession and shadow toll schemes will be 40%. The direct toll range is between 0.06€/vkm and 0.16€/vkm and the shadow toll range between 0.05€/vkm and 0.09€/vkm (MIFO, 2007b).

Growing the private and the freight road transport, traffic congestion, noise and environmental problems become more and more serious problems. The society is assuming directly the environmental and accident costs and indirectly the infrastructure costs mainly paid by the public general expenditure. In economics this costs are included among the social costs, which are defined as the sum of internal and external costs. The internal costs that include mainly time and operation costs, are paid immediately by road users, and external costs that contain maintenance of infrastructure, accident, CO₂ emissions and noise costs, are a burden on society.

Evaluation of internal and external cost is an essential and effective access to make charging on road users. Economic theory suggests social marginal cost pricing as the optimal pricing principle for charging the use of transport infrastructure. Therefore we define and implement a costs model to indicate the more adequate base for a road pricing scheme in Spain.

SCOPE AND METHODOLOGY TO ESTIMATE SOCIAL COSTS

A model for a road social costs estimation

This paper tries to implement a methodology to estimate the social cost of Spanish road systems. The methodology includes the classification of road sections' by

clustering. The conclusions are focused on a proposal of road pricing scheme in Spain.

Marginal costs can be the principle in the case of congestion conditions (Inge et al. 1996). Therefore, the role of average cost in road pricing policy should be considered as well especially in the cases when a road pricing scheme is oriented more for recovering the construction and maintenance of infrastructure than for managing road traffic demand. The aim of cost model is to estimate the external costs produced by the road users and to assign them with a cost equivalent charge. Consequently, it is necessary to consider a formulation that allows assessing the total, average, and marginal costs in order to establish the most adequate toll to internalize the externalities produced by road traffic. The applied methodology defines the total cost function (C_T), which is expressed depending on the hourly traffic flow. Initially, 4 different vehicle categories were considered (a standard private vehicle with a 2 liter engine I_1 , an 18-ton bus for passenger transportation I_2 , an 18-20 ton rigid truck, I_3 , and articulated heavy vehicle for freight transportation, I_4). The final expression for the total costs in euros per vehicle-km is given by:

$$C_T = C_T(I_1, I_2, I_3, I_4) \quad (1)$$

The external costs derived from road traffic can be classified according to their nature as costs, environmental costs (noise, climate change, pollution), costs of accidents and, in some cases, infrastructure (CE Delft, 2008). The final road traffic social cost function is an additive function of these costs:

$$C_T = C_{TO} + C_{cong} + C_{TI} + C_{TENV} + C_{TA} \quad (2)$$

C_{TO}	Operation costs (fuel consumption and travel time)
C_{cong}	Congestion cost: travel time cost during congestion
C_{TI}	Maintenance and operation costs for infrastructure
C_{TENV}	Environmental costs (CO2, atmospheric pollution and noise costs)
C_{TA}	Costs of accidents

Where the marginal external cost, for each kind of vehicle, is obtained deriving the total external costs function.

$$C'_1 = \frac{\partial C_T}{\partial I_1} \quad (3)$$

In this paper we will analyse mainly the external costs, that are the basis for an European road pricing system.

After identifying the different types of road traffic costs, the next step will be to develop individually the formulation of each type of external cost. The congestion cost is formulated like a time operation cost where the marginal time cost is strongly increasing and higher than the average time cost.

Infrastructure Costs

The infrastructures' construction costs are not taken into account in this study because we have considered a complete and already implemented network. This is why the flow of any additional vehicle in the network would not mean a short-term aggravation of these costs. Instead, we have considered the operation and maintenance costs, which depend on the traffic flow.

To simplify, we only assess the maintenance costs related with wear and tear of road pavement, which involve the biggest expenditure for the infrastructure operators. Concretely, we have the formulation proposed by Small, Winston and Evans (19):

$$C_{TI} = K_0 e^{-rT} \quad (4)$$

Where K_0 is a constant determining the maximum cost of conservation, r is the discount rate and T represents the interval of time between maintenance operations. T is specifically determined by means of the following equation:

$$T = \frac{\theta(Q)}{(1 + \alpha)IMD_{VPA} + \alpha IMD_{VRM/A}} \quad (5)$$

Thus, the parameter T depends on the road capacity and the Average Annual Daily Traffic of light and heavy goods vehicles. Variable θ stands for values between 0 and

1, 0 being the most unfavorable situation. Finally, ε is a weighting parameter related with the heavy vehicle axle weight.

For each average cost except maintenance cost depends on hourly flow, while maintenance cost is upon daily flow. The daily flow is a parameter in the maintenance cost equation. Also there is an assumption that the presence of cars brings no extra maintenance cost. They can be ignored in comparison to the cost produced by other vehicles (Bus, LGV and HGV).

Environmental Costs

Environmental costs can be classified into three categories. First, the cost related to CO2 emissions, mainly responsible for the greenhouse effect, is considered. This cost is related to fuel consumption. In order to quantify them, the formulation proposed by Friedrich and Bickel has been considered, since it allows obtaining the cost of climate change in €/h.

$$C_{Env.,CO2} = C_{CO2} \cdot \chi \cdot \sum_{i=1}^{i=4} I_i \cdot Cc_i(v_i) \quad (6)$$

Where I_i is the flow time of vehicle type i ; $Cc_i(v_i)$ is the fuel consumption depending on the speed of vehicle i ; $CCO2$ is CO2 emissions cost ; and K is a constant representing the relation between emissions and consumption.

The next cost to be taken into account regarding environmental costs is the cost related to the noise caused by vehicles. The noise is related to the vehicle flow by a logarithmic function, as considered in Weinberger (1991):

$$L_{eq} = a + 10 \cdot \log(Q \cdot (1 + b \cdot p)) \quad (7)$$

Where L_{eq} is the equivalent noise level, a and b are specific constants in road transportation, q is the overall vehicle flow in the stretch studied and p is the distribution of heavy vehicles regarding the total flow. This formula enables determining the cost associated with this phenomenon by considering the medical costs, since they vary depending on the equivalent noise level. However, because of the logarithmic nature of expression (Baumol, W.J. and W.E. Oates, 1988), a meaningful decrease in vehicle flow has no effect on the equivalent noise level, the variability of noise cost estimated is quite limited between 0.007-0.31 in urban

environment and 0.01 and 0.02 in the interurban environment, similar to the noise costs estimations realized in some others studies (CE Delft et al 2007; Infras 2004; Unite 2003) estimated between 0.008-0.034 €/veh-km in urban environment and 0 in the interurban environment.

Finally, atmospheric pollution costs in euros per vehicle-mile derived from particle emissions are considered as well. The atmospheric pollution cost depends on the population (P_t); the average value ϕ of the PM10 immissions (particles below 10 microns); the amount of new cases per million inhabitants from the new effects j ($j = 1, \dots, 8$), which are considered to be the consequence of a PM10 level of $10 \mu\text{g}/\text{m}^3$ a year (n_i); and the cost on human health 1 each of these effects carry along, according to the following expression:

$$CT_{Env,p} = \frac{P_t * \phi * \sum_{i=1}^m n_i c_i}{10} \quad (8)$$

Accident Costs

External costs caused by road accidents have been considered as regards the slightly injured, seriously injured and killed in an accident ratio (r_{sl} , r_{se} , r_k), and as regards the value associated with each type of casualty. Thus, the expression formulating the costs derived from road accidents becomes linear as regards vehicle flow:

$$CT_{acc} = I_1 \times (R_{hl} \times VR_{hl} + R_{hg} \times VR_{hg} + R_m \times VR_m + \phi) \quad (9)$$

Where I_i represents the traffic flow in vehicle i , r is the risk associate to the different types of accident victims and V the monetary value associated to those types of victims.

The major external costs depend on the fuel consumption and time cost. Both are related with the speed, using the relationship between speed and hourly flow (Transportation Research Board, 2000), knowing the AADT data, we can estimate the most important variable costs.

$$\frac{FuelCons}{Km} = a_0 + \frac{a_1}{V} + a_2 V^2 \quad (10)$$

The parameters a_0 , a_1 , a_2 are estimated for each type of vehicle following their technical characteristics.

From the traffic fundamental equation between traffic volume and density (11) as well as the parabolic relationship between traffic volume and speed, we obtain (12).

$$I_h = D \cdot v \quad (11)$$

Therein I_h is the average hourly volume per lane (veh/h/lane), D is the traffic density (veh/km/lane) and v is the average travel speed (km/h). Therefore, v could be expressed as a function of I_h :

$$v = 0,5 * v_{\max} \pm 0,5 * [v_{\max}^2 - (4 * I_h * v_{\max} / D_{\max})]^{0,5} \quad (12)$$

Therein v_{\max} is the maximum travel speed (km/h) and D_{\max} is the traffic maximum density (veh/km/lane).

In this way, if we estimate the hourly flow, by equation 12, we can estimate the fuel consumption for each vehicle, and consequently mainly operation and external costs.

$$I_h = AADT \times \left(\frac{k}{d} \right) \times \eta \quad (13)$$

Where: -

- the parameter "k" is IMD's proportion that is realized in rush hour,
- the parameter "d" is IMD's proportion in rush hour and sense top, and
- the parameter "η" is the number of total lanes.

Basically, each cost term depends on vehicle hourly volume I_{hi} that we can calculate by the daily flow that is a known variable by the data map elaborated by the Spanish Ministry of Public Works.

The Cluster Analysis of Spanish Road Network

The Spanish interurban road network has been represented using Geographic Information Systems (GIS). We have generated a digital network that covers the whole Iberian Peninsula and the French regions bordering Spain, to include also the border effects (Gutierrez, J., A. Condeço and J.C. Martín, 2010). This network contains all the roads managed by the Spanish Ministry of Public Works and the main roads belonging to the Regional governments as well.

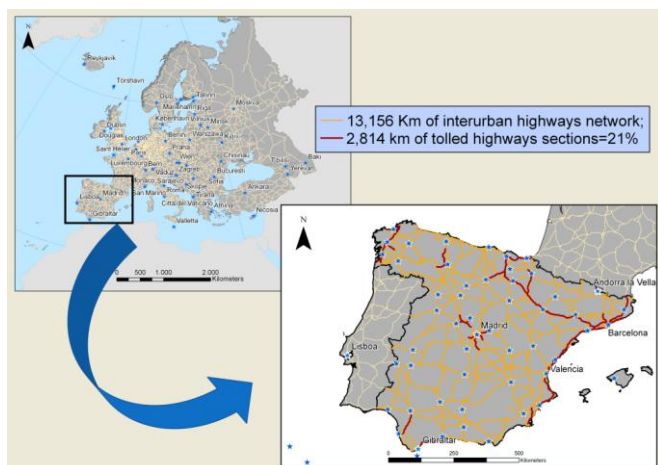


Figure 1: Spanish Interurban Highways network (META 2008)

In Portugal and the French regions this graph includes the main roads. The final result is a dense network with more than 6,355 links covering a wide territorial area. This study focuses on interurban roads, the interest is to implement the model of social costs to estimate the cost-type of each road section of the network. We decide to classify the different roads by using a clustering process. For every road type, external cost is different even if sections' traffic volume is the same, and it has different capacity and number of lanes, which are parameters in the cost model. The first step is to divide road types according to the number of lanes. Three attributes including POF_i (Proportion of *i* section's flow in maximal flow), POH_i (Proportion of *i* section's flow of HGV in total flow) and floating vehicles speed (a proxy of space speed) are chosen to cluster each road type. For every clustering there are a maximal density and speed which are defined in equations (10)-(13) respectively. Here those three attributes can be regarded as three vectors of each section. A clustering process means to measure the distance between every section and regroup the most nearest sections to the same cluster.

Taking sections from 2+2-highways as an example, Figure 2-a shows the space location of those sections according the three attributes, Figure 2-b is the projective graphs of figure 2-a: the distribution of those sections from 2*2 lanes is concentrative, like the POF range from 0% to 20%, the range of POH is from 10% to 30% and the range for space speed is 100km/h to 130km/h.

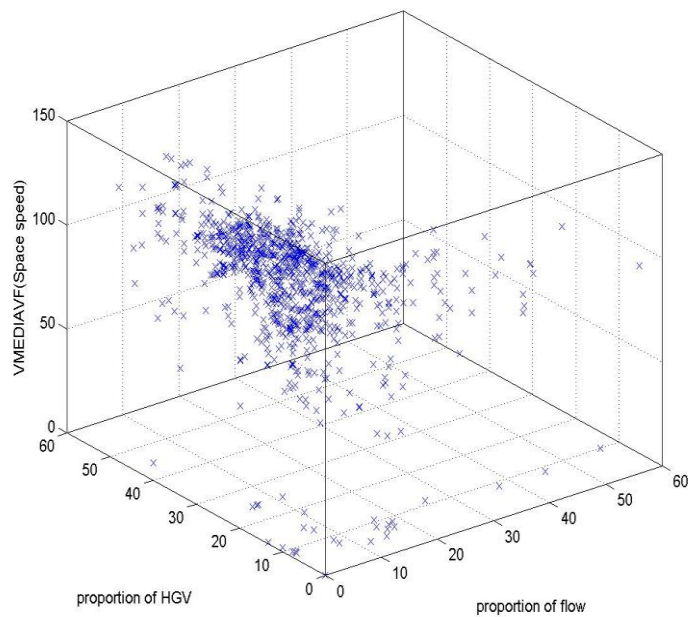


Figure 2-a space location -2+2 highways

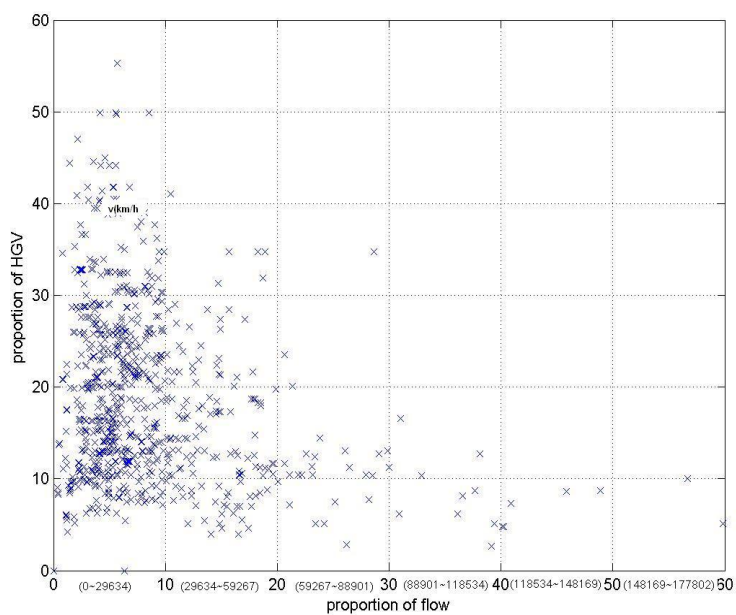


Figure 2-b Projective location -2+2 -highways

Through this methodology we have been able to organize the road section into groups with comparable characteristics according to different criteria, traffic flow, percentage of heavy vehicles and floating vehicle speed, which determine the traffic costs.

The most important result derived from using the cluster analysis is the choice between two different groups of road sections for each level of the road network:

- **Standard highways sections group:** representative of the specific characteristics of most sections of the type of roads under consideration;
- **Intensive-Use highways sections group:** contains the sections characterized by special traffic conditions (e.g. strong percentage of heavy vehicles, congestion)

These groups will be used as a reference for estimating the cost-type of each representative section and establishing the corresponding toll values.

Table 1: Classification of standard and intensive-use highways

Standard and intensive-use road sections groups for 4-lane- 2+2-highway-					
Groups	POFa (%)	ADDT ^b (veh/day)	PO h ^c (%)	s ^d (km/h)	sections (n)
Standard	(0-10)	(0-30,000)	(10-20)	(100-130)	347
Intensive-use (strong percentage of HGV)	(0-10)	(0-30,000)	(30-50)	(100-130)	181
Standard and intensive-use road sections groups for 6- lane- 3+3-highway-					
Groups	POFa (%)	ADDT ^b (veh/day)	PO h ^c (%)	s ^d (km/h)	sections (n)
Standard	(10-30)	(30,000-90,000)	(0-30)	(100-130)	110
Intensive-use (congestion)	(30-50)	(90,000-150,000)	(10-20)	(80-110)	3
Standard and intensive-use road sections groups for 8-lane- 4+4-highways					
Groups	POFa (%)	ADDT ^b (veh/day)	PO h ^c (%)	s ^d (km/h)	sections (n)
Standard	(10-30)	(30,000-90,000)	(10-30)	(90-120)	21
Intensive-use (congestion)	(30-40)	(90,000-120,000)	(10-20)	(40-90)	5

Note: a. $POF = [AADT / \text{Max AADT}] * 100\%$, Proportion of Flow; b AADT is Annually Average Daily Flow; c. $POH = [\text{Flow of HGV} / (AADT)] * 100\%$, Proportion of HGV; d. SS is space speed(km/h).

ANALYSIS OF RESULTS

Applying the model described above to Spanish road data, average and marginal social costs of four types of vehicles are calculated. We present 2+2 highways as an example because they are more representative of the specific characteristics of the type of roads under consideration (90% of whole Spanish road network). The analysis and the discussion of the social costs are focused on the light (cars) and heavy vehicles (trucks and buses flow costs are very similar).

Figure 3 and 4 show the average social costs estimated for cars and HGV for both road sections groups of 2+2 highways: standard and intensive-use. As shown above in the presentation of the costs model, social costs include internal (time and operation costs) and external costs (accidents, CO₂ emissions, pollution and noise costs). The cost of time is a measure of the congestion cost, equivalent to the time lost due to the decrease in speed for all vehicles because of the incorporation of new users. In the representative clustering the average time cost is constant (free flow speed), while in the intensive-use road sections group it is higher and increasing with the growing flow because of the stronger proportion of HGVs (Fig. 3 and 4). In particular, in the case of heavy vehicles, the increasing flow produces an increasing time cost and, at the same time, decreasing fuel costs. The final result, in terms of internal costs, depends on the sum of changes in time and fuel costs. Hence, roads with a larger proportion of HGVs may more easily fall into congestion.

We find this same kind of behaviour for the costs for cars in the case of 4+4-highways that represents the road sections closed to the metropolitan area where the proportion of car traffic is stronger and the congestion point easily reachable (Fig. 5). It is noticeable that operation costs mainly based on the fuel consumption are basically proportional to the speed until the congestion situation is reached. In fact, an increasing flow produces a decreasing average speed and a diminishing fuel cost. Average CO₂ and accident costs are constant in no congestion situations and directly related with the speed.

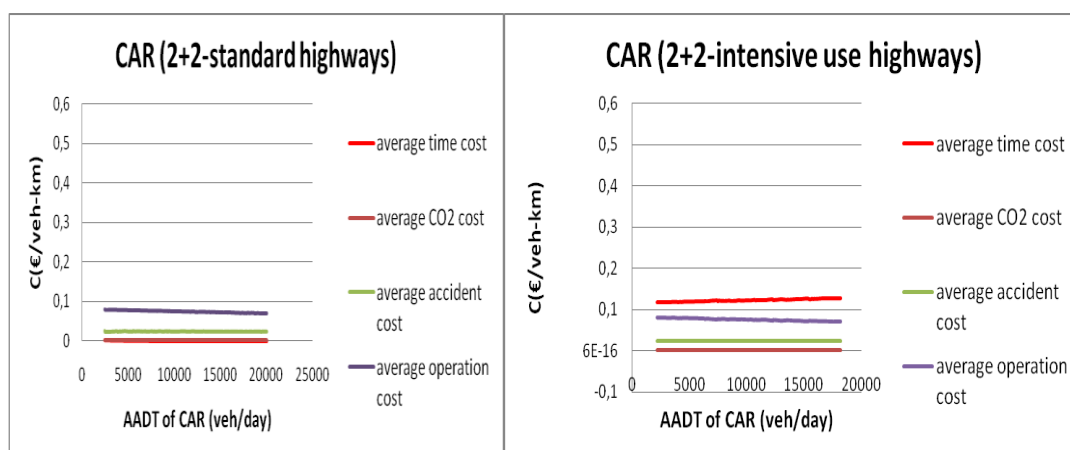


Figure 3 average cost of CAR from standard and special sections of road selected -2+2 highways

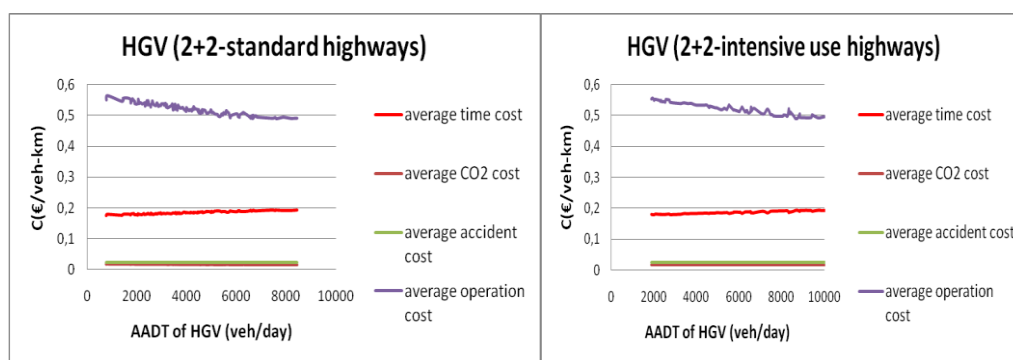


Figure 4 average cost of HGV from standard and special sections of roads selected -2+2 highways

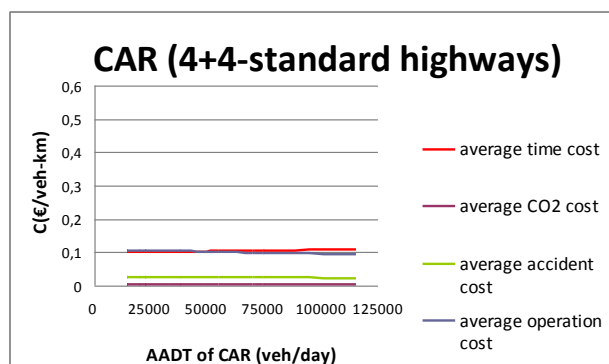


Figure 5 average cost of CAR from standard sections of road selected -4+4 highways

The average noise and pollution costs are the same for all kinds of vehicles, since our cost function does not permit to precisely attribute the noise produced to a specific kind of vehicle. We can differentiate the noise for a given proportion of heavy vehicles. Therefore, an important difference exists between the noise costs registered for the 2+2 standard highways and for the 2+2 intensive-use highways where a higher level of HGV is used for noise cost estimation. Actually, the trend of the cost of noise is more irregular for the intensive-use road sections group; in

general, the noise cost is higher with a stronger HGV traffic flow. An interesting result derives from estimating the noise and CO₂ costs for 4+4 intensive-use highways: in this case, where the traffic is composed mainly by cars with a low percentage of HGV, the noise costs are lower and rapidly decreasing.

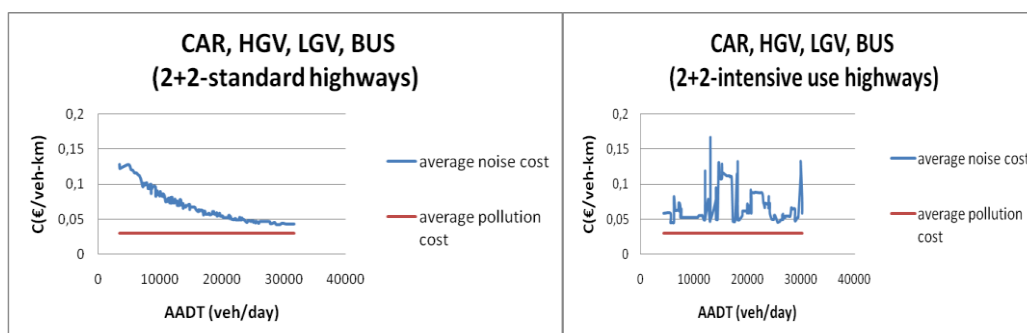


Figure 6 noise and pollution costs of vehicles from standard and special sections of roads selected -2+2 highways.

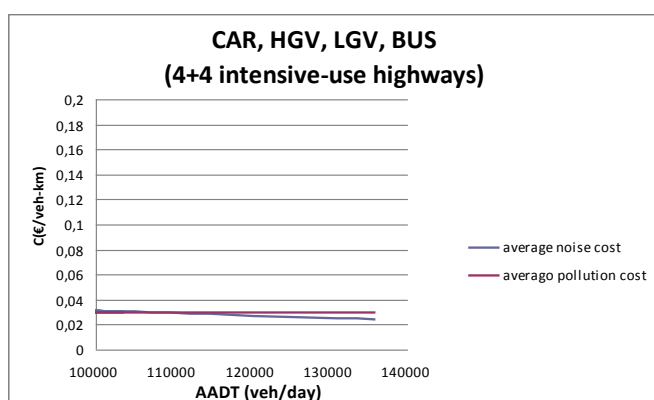


Figure 7 noise and pollution costs of vehicles from intensive-use sections of roads selected - 4+4 highways.

The difference between the average internal cost and the average social cost represents the external costs which are a burden on society. Figure 8 shows the average internal and social costs of cars. The social costs are constant as the flow of traffic grows. In a situation of “no congestion”, the gap between the average social and internal costs represents the cost which road users should pay.

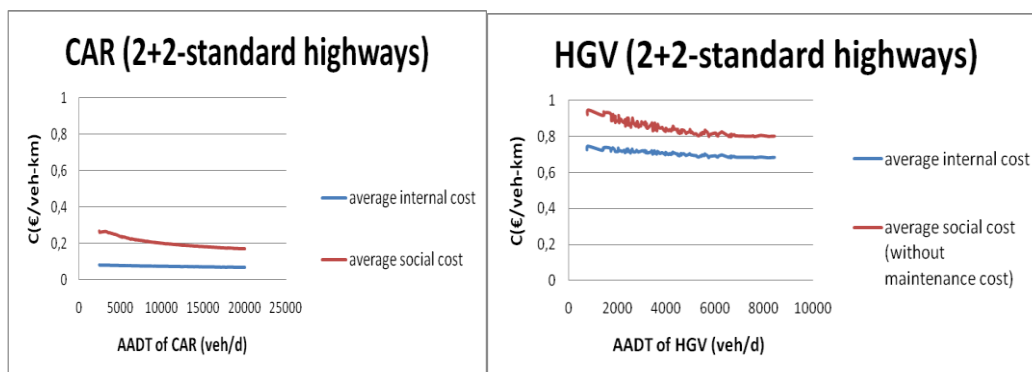


Figure 8: Comparing social and internal costs for Car and HGV on 2+2 highways.

A social costs comparison

Comparing the results presented in table 2 on the social costs of cars, we can draw interesting conclusions about the current road social costs and their policy implications.

First, the internal operation costs for the car are lower than the external costs. That means that the costs produced by a car and paid by society are bigger than the current costs paid by a private road user. This result is related to the low congestion rate of the interurban network, i.e. the high average speed that produces an important saving of travel time. In this case, the saving produced in travel time is bigger than the higher rate of fuel consumption related to a higher speed. Hence, the user has a small incentive to modify his behavior faced with the utilization of the car, while the society pays the bigger burden of the social cost. If we remind that the 2+2 standard highways represent 90% of the whole Spanish road network, the implication of these sharing of the social costs between private user and society is relevant. A road pricing aiming the internalization of the external costs has a very good reason to exist.

If we compare these results with the 4+4- intensive use case, the internal operation costs increase because of the increasing travel time, but the external costs are lower because of the lower consumption of fuel and the increased traffic flow. In this situation, the roads are working near to the point of constant economies of scale and the social optimal is financially viable.

Table 2: Average costs for car use

Type of Highways	Operation costs (time and fuel) (€/v-km)	External Costs (Co2, pollution, noise, accident) (€/v-km)	Social costs
2+2-standard	0.08	0.12	0.20
2+2-intensive use	0.198	0.11	0.31
3+3-standard	0.20	0.08	0.28
3+3-intensive use	0.20	0.075	0.275
4+4-standard	0.20	0.06	0.26
4+4-intensive use	0.20	0.056	0.256

In the case of the HGV (table 3) the road system is always operating with economies of scale that remain constant. The share of the social costs attributed to internal and to external and infrastructural costs is inverted in respect of the case of car in 2+2 standard highways: the internal operation costs are always higher than the external and infrastructure costs. Obviously, the costs of infrastructure maintenance are higher in the case of 2+2 “intensive-use” highways where the proportion of HGV traffic is stronger. In the case of HGV the implementation of a road pricing scheme will be useful to pay the use for the highways and to indemnify the society for the damage produced by the external costs, but not specifically to incentive HGV road users to change their travel behavior.

Table 3: Average costs for HGV

Type of Highways	Maintenance infrastructure costs (€/v-km)	Operation costs (time and fuel) (€/v-km)	External Costs (Co2, pollution, noise, accident) (€/v-km)	Social costs
2+2-standard	0.021	0.71	0.138	0.869
2+2-intensive use	0.023	0.73	0.108	0.861
3+3-standard	0.015	0.85	0.12	0.985
3+3-intensive use	0.003	0.59	0.096	0.689
4+4-standard	0.033	0.89	0.083	1.006
4+4-intensive use	0.011	0.82	0.10	0.93

META: A ROAD PRICING MODEL PROPOSAL

The Spanish road pricing model project (META) proposes a vehicles tolling scheme aimed at recovering the cost for highway maintenance and operations as well as external costs. The META road pricing scheme proposed for the Spanish interurban road network is based on average costs calculated for each vehicle type (Car HGV, LGV and bus) following the interurban road characteristics (AADT, capacity and traffic composition for each section). As showed in Figure 1, for the Spanish interurban highways, mostly characterized as 4-lane - 2 plus 2- highways, congestion is not a current problem. Therefore the marginal external cost is equal to the average external costs or even stays below the average external costs. In other words, the Spanish interurban roads, outside of the major metropolitan areas, are underused. That means that the road system is operating with increasing economies of scale (the system will be more efficient if more cars use the Spanish road network).

To cover the external costs produced by a car user it is necessary to fix the toll so that it equals the average external costs. The case is slightly different when there is a comparison between marginal external and infrastructural cost and average external and infrastructural cost for the HGV, and where both costs are the same. This means that in the case of the HGV, the road system is operating with economies of scale that remain constant, the social optimal is financially viable, while the correct solution to determining tolls for private cars will be imperfect because the condition of economic

efficiency -- with a toll equal to the marginal external cost is not attainable. In fact, the system is unable to finance itself: somebody has to pay to cover the difference between average external costs and marginal external costs (Jara-Díaz, 2007). Two alternatives: the private car users pay a toll equal to the average external costs or the society as a whole decides to pay a part of the external costs (Fang, J., F. Di Ciommo, A. Monzon, 2009).

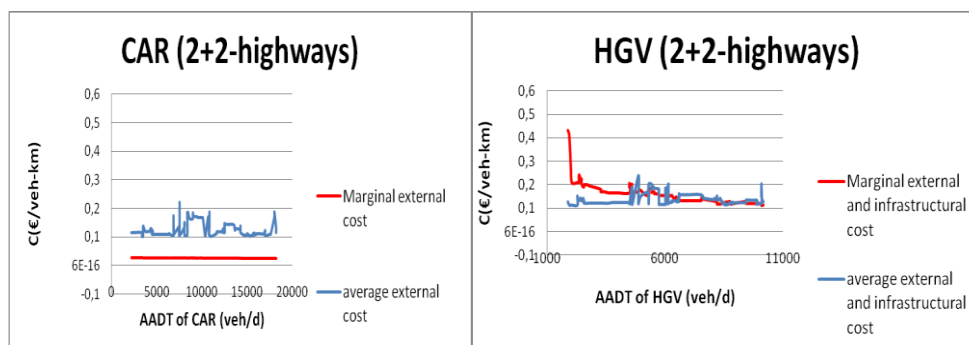


FIGURE1. Marginal and average external road transport costs comparison in 2+2- highway

Following this empirical model for costs, the proposal for a toll scheme should include a price range for roads (2+2 - highways) of 0.09€ per car-km to 0.14€ per HGV-km. It is said that the marginal cost should be the road pricing principle. It is clearly the best in the congested situation. However the Spanish road situation is not so bad according to our analysis. Marginal cost is not so important and average cost would be more attractive, average cost will be higher than marginal cost in low congestion situations, which will be more consistent with real situation. In consequence, we conclude that the average cost can be used instead of marginal cost to define a road pricing policy.

CONCLUSIONS

The research carried out shows clearly that marginal cost principle is not suitable for all situations. Average costs should also be applied to have a more accurate reference for road pricing determination. Any kind of social cost of HGV, LGV and BUS are bigger than those related to cars because of the maintenance costs and the higher operation costs.

In this paper we analyze the current situation of the Spanish interurban road network and we estimate the social costs produced by different road users (basically cars and HGV). The main result is that 90% of the Spanish interurban highways network does not suffer a congestion problem. Two main consequences derive from this situation:

1. The basis of road pricing has not to be necessarily the marginal social costs. We can use average social costs because the marginal and average costs are constant and similar;
2. 70% of the whole interurban highways network is underused. In the case of the 2+2 standard highways type, we face a very surprising result: the internal cost is lower than the external cost produced by a car. This implies that the car users have not the price incentive to correctly use the road. They need to pay for the external costs to perceive the cost nearest to the real cost produced by a trip.
3. The composition of the internal costs between fuel and time changes, following the floating vehicle speed (table 2): when the traffic flow is very low, the consumption of fuel is higher, but the travel time cost is very low. With an increasing traffic flow the situation is inverted, but the internal cost is the same, except for the car in the case of 2+2 standard highways.

Concerning HGV traffic, the cost of maintenance infrastructure is higher for 2+2 intensive-use highways, while the internal costs increases with an increasing traffic flow because of the higher travel time costs. In the context of 2+2 standard highways, car users have very little incentive to modify their behavior, while the society is charged by the bigger burden of the social cost. If we recall that the 2+2 standard highways represent 70% of whole Spanish road network, the implication of this sharing of the social costs between the private user and society is relevant. A road pricing aiming at the internalization of the external costs has a very good reason to exist. Within the European Union framework, this is a very relevant result that should reinforce the purpose to apply a generalized road pricing scheme to all types of vehicles, including private cars.

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